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Im Auftrag

For the President of the European Patent Office

Le Président de l'Office européen des brevets
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Display screen comprising a plurality of cells

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Display screen comprising a plurality of cells

The invention relates to a display screen comprising a plurality of cells. The invention also relates to a display system having a display screen comprising a plurality of cells and to a set of display screens.

US 5,612,798 discloses a display device comprising liquid crystal material and an array of photocells. A scanning laser scans the array of photocells, thereby illuminating each photocell to a different degree. In dependence on the illumination each photocell accumulates charge, thereby generating an electrical field, which influences the polarization of the liquid crystal material near the photocell. In combination with a polarizer, the material near the photocell forms a pixel which is able to modulate light, originating from a light source and passing through the pixel, in dependence on the electrical field. After the laser scanner has scanned a photocell, the charge gradually dissipates. As a result the pixel modulates light in dependence on the intensity of the illumination. When repetitively scanning the photocell coupled to the pixel, the amount of modulation depends on the charge remaining from a previous scanning operation. This effect reduces the image quality. It is a disadvantage of the display device that the image quality is not optimal because the amount of modulation depends on the charge remaining from a previous scanning operation.

It is a first object of the invention to provide a display screen of the kind described in the opening paragraph, which enables a modulation of light by a pixel as result of an optical display signal, which is relatively independent of a preceding optical display signal.

It is a second object of the invention to provide a display system of the kind described in the opening paragraph, which enables a modulation of light by a pixel as result of an optical display signal, which is relatively independent of a preceding optical display signal.

It is a third object of the invention to provide a set of display screens of the kind described in the opening paragraph, which enables a modulation of light by a pixel as result of an optical display signal, which is relatively independent of a preceding optical display signal.

The first object is realized in that each cell comprises a pixel for modulation of light from a light source, a photosensitive device for converting optical display signals into an electrical signal to control the modulation by the pixel, a storage capacitance coupled in parallel to the photosensitive device and a storage reset switch for providing a storage reset voltage to the storage capacitance. The electrical signal of the photosensitive device discharges the storage capacitance in dependence on the optical display signals and controls the modulation by the pixel. After providing a storage reset voltage via the storage reset switch to the storage capacitance, a substantially well defined voltage is present across the capacitance. So, optical display signals received by the photosensitive device after the storage reset voltage has been provided, result in a modulation by the pixel starting from the substantially well-defined voltage across the storage capacitance and therefore result in a substantially well defined modulation.

A cell may comprise more than one pixel, while each pixel in this cell may be coupled to one or more photosensitive devices. Alternatively, a cell may comprise more than one photosensitive device, while each photosensitive device in this cell may be coupled to one or more pixels.

It is advantageous if the storage capacitance is formed by a parasitic capacitance of the pixel, and the pixel is coupled in parallel to the photosensitive device. No extra capacitor is required, which results in a simple and cost effective embodiment. By means of the storage reset voltage the pixel may be put into a substantially light blocking state. Thereafter, in dependence on the intensity of the optical display signals, the photosensitive device gradually discharges the storage capacitance, thereby reducing the voltage across the pixel. As a result, in dependence on the characteristics of the pixel, the modulation by the pixel gradually changes from blocking the light from the light source to partially transmitting, or reflecting, the light. So, the pixel becomes gradually brighter.

The pixel may comprise any type of liquid crystal material. Such a liquid crystal pixel may be of a transmissive type, which is capable of modulating light transmitted through the pixel, or of a reflective type, which is capable of modulating the reflection of light falling onto the pixel. It is advantageous if the pixel comprises Super Twisted Nematic Liquid Crystal material. This material has a relatively steep transmission versus voltage

characteristic. This reduces the voltage range required across the pixel to vary the modulation from blocking to full transmission. As a result the required amount of charging and discharging of the parasitic capacitance of the pixel by the photosensitive device is reduced. This means that by using the mentioned liquid crystal material, the requirements on the efficiency of the photosensitive device or the intensity of the optical display signal are reduced. The requirements may further be reduced by the use of liquid crystal materials that have a relatively low dielectric constant and/ or have a relatively large cell gap.

In an embodiment storage reset means are present for providing a storage reset signal to each storage reset switch of a number of the plurality of cells to put each pixel of the number of the plurality of cells in a substantially light-blocking state. A number of the plurality of cells may be located in any way, for example the number may comprise the cells in an upper part or a lower part of the screen, the cells of one or more rows, the cells of one or more columns or cells of a particular type, for example of a particular color.

The storage reset signal may be applied repeatedly, for example, at the start of a frame period of the optical display signals. As a result the storage capacitance is charged to a voltage causing the pixel to be in a light blocking state. During the remainder of the frame period the photosensitive device discharges the capacitance in dependence on the optical display signals received by the photosensitive device. If the photosensitive device receives optical image signals during a large part of the frame period, then the corresponding pixel becomes gradually brighter during that frame period. Before a next image is displayed during a next frame period, the storage reset signal is applied again. In this way moving images, formed by a sequence of images at a rate equal to the frame rate, may be displayed on the screen. As the pixels become gradually brighter during a frame period, they are perceived as providing a pulsed light output, which reduces motion blur problems.

In an embodiment each of the plurality of cells further comprises a driver circuit coupled between the photosensitive device and the pixel, while the storage capacitance is formed by a storage capacitor. The driver circuit may be adapted to generate a desired level of the electrical signal provided to the pixel, so the amount of modulation of the light by the pixel in response to the optical display signals received by the photosensitive device is less restricted by the characteristics of the pixel and the photosensitive device. So, the pixels may, for example, comprise liquid crystal material which has a less steep transmission versus voltage characteristic, while providing an improved grey scale, a wider viewing angle or other performance improvements.

In each cell the driver circuit may comprise a drive transistor having a control terminal and a first and a second main terminal, the storage capacitor having a first and a second terminal, the first terminal of the storage capacitor being coupled to the control terminal of the drive transistor, and the first main terminal of the drive transistor being coupled to the pixel. The drive transistor operates as a current source which charges or discharges the pixel. If the pixel comprises a liquid crystal layer, the drive transistor charges or discharges this layer.

In each cell the second main terminal of the drive transistor may be coupled to a first supply voltage, and the second terminal of the storage capacitor may be coupled to a reference voltage. Such an arrangement allows selecting the operating range of the photosensitive device, which is coupled in parallel to the storage capacitor, independently of the first supply voltage.

In a variation of the embodiment each cell further comprises a pixel reset circuit coupled between the first main terminal of the drive transistor and the pixel. The pixel reset circuit resets the pixel, for example by resetting the voltage across the pixel to a value, at which the pixel substantially blocks the light from the light source. By means of this resetting the pixel is brought in a predefined state, which means that any modulation by the pixel after the resetting is substantially independent of the history of the pixel.

In each cell the pixel reset circuit may comprise a first transistor and a second transistor, each having a control terminal, a first main terminal and a second main terminal, the first main terminal of the first transistor being coupled to the first main terminal of the drive transistor, the second main terminal of the first transistor and the second transistor being coupled to the pixel, the control terminals of the first transistor and the second transistor being coupled to receive a pixel reset signal, and the first main terminal of the second transistor being coupled to receive a pixel reset voltage. The pixel reset circuit provides the pixel reset voltage to the pixel in dependence on the pixel reset signal. While the pixel reset voltage is coupled via the second transistor to the pixel, the first transistor blocks the current flow from the drive transistor to the pixel. So, any current originating from the drive transistor during the resetting, does not disturb the resetting of the pixel.

It is advantageous if the display screen further comprises pixel reset means for providing the pixel reset signal to each pixel reset circuit of a number of the plurality of cells for putting each pixel of the number of the plurality of cells in a substantially light-blocking state; and storage reset means for providing a storage reset signal to the first terminal of each storage capacitor of the number of the plurality of cells, substantially synchronously with the

pixel reset signal, for substantially turning off the drive transistor. In this event, simultaneously the number of the plurality of cells is reset, by resetting the voltage across the storage capacitor as well as the voltage across the pixel.

The photosensitive device may be selected from a poly-Silicon phototransistor, an amorphous-Silicon phototransistor and a PIN diode. The photosensitive device may also be a poly-Silicon phototransistor or an amorphous-Silicon phototransistor coupled as a diode by a connection between the control electrode and a main electrode.

The display screen of the invention may have a front side for delivering light modulated by each pixel of the plurality of cells, each photosensitive device of the plurality of cells being adapted to receive the optical display signals from a source positioned at a side of the screen facing away from the front side. Applying rear projection has the advantage that the source of the optical display signals is hidden behind the screen.

Alternatively the screen may be arranged for front projection, the photosensitive device being located at the front side. Front projection and rear projection may be applied in combination with pixels of the transmissive type or pixels of the reflective type.

It is advantageous if each photosensitive device of the plurality of cells of the screen of the invention is adapted to receive optical display signals of non-visible light. By applying a source, which generates optical display signals outside the visible light spectrum, interference between the optical display signals and visible light modulated by the pixels in the screen is avoided. Moreover such a screen is not sensitive to ambient lighting conditions.

The second object is achieved in that the display system comprises a display screen as described before and an optical image source for transmitting optical display signals to the photosensitive devices.

The optical image source may be selected from a projection device and a laser scanner.

In an embodiment the pitch of the cells of the screen is smaller than the pitch of the picture elements of a highest resolution image which the optical image source is capable of projecting on the screen. In this embodiment the optical image source may generate any format image from a low resolution up to the highest resolution. The display screen then is capable of reproducing each of the picture elements of the highest resolution image projected on the screen. If an image with a resolution lower than the highest resolution is projected on the screen, then for each picture element several cells are available for generating the light corresponding to that picture element. In this case, if one of the several

cells would fail, then only the brightness contribution of the cell that failed will be lost in the light for reproducing that pixel element.

The third object is achieved in that the display screens of the set of display screens are arranged adjacent to each other in a tiled pattern. As each display screen has only a small number of connections, this number being in the order of less than 10, it is relatively easy to interconnect corresponding connections of a set of displays. Due to this small number of connections it is also relatively easy to align display screens in a tiled pattern adjacent to each other.

These and other aspects of the screen and system of the invention will be further elucidated and described with reference to the drawings, in which:

Figs. 1A to 1C show block diagrams of embodiments of a cell applied in the display screen according to the invention;

Fig. 1D shows a block diagram of an embodiment of the display system according to the invention;

Fig. 2 shows a transmission characteristic of a pixel comprising liquid crystal material;

Fig. 3 shows a more detailed schematic diagram of an embodiment comprising a cell 2 as shown in Fig. 1A;

Fig. 4 shows waveforms of the diagram of Fig. 2;

Fig. 5 shows a more detailed schematic diagram of another embodiment comprising a cell 2 as shown in Fig. 1A; and

Fig. 6 shows waveforms of the diagram of Fig. 5.

The same references in different Figs. refer to the same signals or to elements performing the same function. The embodiment of a cell 2 applied in the display screen according to the invention as shown in Fig. 1A comprises a photosensitive device D and a pixel P. The photosensitive device D receives optical display signals Li, for example from an optical image source. The optical display signals Li, which may be formed by light within or outside the visible spectrum induces a photo-current in the photosensitive device D. The electrical signal I, which changes the transmission, or reflection, of the pixel P, may be formed by the photocurrent, or may be obtained by amplification of the photocurrent. As a

result the pixel P modulates light originating from a light source (not shown) in dependence on the electrical signal I, which in turn depends on the external control signal Li.

In Fig. 1B an embodiment of a cell 2 is shown comprising several photosensitive elements D1, D2, D3, D4. These photosensitive elements D1, D2, D3, D4 are connected to one pixel P. Alternatively (not shown), one or more of the photosensitive elements D1, D2, D3, D4 may be connected to one or more driver circuits A, while each driver circuit A is coupled to the pixel P.

In Fig. 1C an embodiment of a cell 2 is shown comprising a photosensitive device D and several pixels P1, P2, P3. Each of these pixels P1, P2, P3 is modulated by the photo-current of the photosensitive device D.

The display system 6 shown in Fig. 1D comprises a display screen 5 and an optical image source 3. The display screen comprises a display panel 1, storage reset means SRM for providing a storage reset signal SRS and pixel reset means PRM for providing a pixel reset signal PRS. Both reset means SRM, PRM may be dedicated hardware circuits, such a signal generators, but may also be comprised in timing and control circuitry providing waveforms with an appropriate timing and amplitude. Alternatively, a processor may perform the function of both reset means SRM, PRM.

The display panel 1 comprises a plurality of cells 2 arranged in a matrix of rows and columns. The panel 1 does not require any row or column electrodes as each cell 2 is addressed via an external optical image source 3. For this reason the cells 2 may be arranged in any arbitrary configuration, so apart from a configuration in rows and columns, also other configurations like, for example, radial, diagonal or circular configurations may be applied. The cells 2 may also have a large variety of shapes. The panel 1 has connections for receiving the storage reset signal SRS and the pixel reset signal PRS. Moreover the panel 1 has connections for receiving voltages:

a reset voltage VR,

a first supply voltage V1,

a second supply voltage V2, which may be ground level, and

a pixel reset voltage VPR.

The panel 1 may also have an additional connection for receiving a reference voltage Vref.

The reset signals, the voltages and the reference voltage Vref if present, are coupled to each cell 2 of the panel 1.

Each cell 2 receives corresponding optical display signals Li from the source 3. Via the photosensitive device D in a cell 2 the optical display signals Li are converted into the electrical signal I. The pixel P in that cell 2 modulates light originating from a light source 4. This may be done in a known manner, in which a voltage change across a layer of liquid crystal material changes the polarization of light transmitted through, or reflected by, the liquid crystal layer. In combination with a polarizer the change of polarization results in a change of the intensity of the light transmitted through the combination of the liquid crystal layer and the polarizer. An example of a transmission curve is given in Fig. 2. The curve shows the percentage of light transmission (TP) as function of the voltage (VP) across the pixel P. In the shown curve the pixel blocks the light from a light source, so is non-transmissive, when the voltage VP across the pixel is 5V or larger. Between voltages VP of 2V to 5V the transmission varies between 100% and 0%. In the voltage range -2V < VP< 2V the pixel is transmissive, while in the range from -2V till -5V the pixel becomes gradually non-transmissive again. So, the operating range may in the range of -2V to -5V or in the range of +2V to +5V as indicated by the arrows in Fig. 2.

Fig. 3 shows a more detailed schematic diagram of an embodiment comprising a cell 2 as shown in Fig. 1A. The diagram comprises the photosensitive device D coupled in parallel to the pixel P having a first terminal and a second terminal. The pixel P in this embodiment comprises a layer of liquid crystal material. The storage capacitance is formed by the parasitic capacitance across the liquid crystal layer of the pixel P. The first terminal of the pixel P is coupled via the main terminals of a storage reset switch SR to a reset voltage VR. A control terminal of the storage reset switch is coupled to receive the storage reset signal SRS from the storage reset means SRM. The second terminal of the pixel P is coupled to the first supply voltage V1. The electrical signal I is in this embodiment formed by a photo current generated by the photosensitive device D and discharging the pixel P.

The operation of the cell 2 will be explained below with reference to the waveforms as function of time t as shown in Fig. 4.

During a reset time interval TR the reset switch SR is closed by the storage reset signal SRS, as indicated by a high level of the reset signal RS. Via the reset switch SR the storage reset voltage VR, which may be a fixed voltage, is coupled to the first terminal of the pixel P. As a result the control voltage VD at the first terminal of the pixel P will quickly reach the level of the reset voltage VR. The reset voltage VR is in this embodiment lower than the first supply voltage V1. For example, for a pixel with a transmission curve as shown in Fig. 2, the storage reset voltage may be selected to be 5V lower than the first supply

voltage V1. During the display time interval TD the optical display signals Li received by the photosensitive device D result in a photo-current, indicated by an arrow I in Fig. 3, which discharges the storage capacitance formed by the pixel P. When no optical display signals Li are received the storage capacitance is not discharged, so the control voltage VD remains constant, and the transmission TP remains substantially 0%, as indicated by the curves "Li=0" in Fig. 4. When the optical display signals Li correspond to a maximum level Lmax, the storage capacitance is substantially completely discharged during the drive time interval TD, resulting in the curves of the control voltage VD and the transmission TP indicated by "Li=Lmax". When the optical display signals Li correspond to a level in-between zero and the maximum level Lmax, the storage capacitance is partially discharged during the drive time interval TD, resulting in the curves indicated by "0<Li<Lmax".

So, the level of light Lo transmitted by the pixel P is proportional to the optical display signals Li. A display screen 5 equipped with such cells 2 displays a positive image of an image projected on the screen by the source 3.

Fig. 5 shows a more detailed schematic diagram of another embodiment comprising a cell 2 as shown in Fig. 1A. The main differences with respect to the diagram shown in Fig. 3 are:

The storage capacitance is formed by a separate storage capacitor C having a first terminal coupled to a reference voltage Vref different from the first supply voltage V1, while the photosensitive device D is coupled in parallel to the storage capacitor C.

The pixel P is coupled in series with the driver circuit A, which in this embodiment comprises a drive transistor DT. The drive transistor DT has a first and a second main terminal and a control terminal. The storage capacitor C has a second terminal coupled to the control terminal of the drive transistor DT. The first main terminal of the drive transistor DT is coupled to the first supply voltage V1.

The second main terminal of the drive transistor DT is coupled via a pixel reset circuit PRC to a first terminal of the pixel P. The pixel P has a second terminal coupled to a second supply voltage V2, which may be ground level.

Pixel reset means PRS are present for providing a pixel reset signal PRS to the pixel reset circuit PRC.

The pixel reset circuit PRC comprises a first transistor T1 and a second transistor T2, each transistor T1, T2 having a first terminal, a second terminal and a control terminal. The first main terminal of the first transistor T1 is coupled to the first main terminal of the drive transistor DT, the second main terminal of the first transistor T1 and the second

transistor T2 are coupled to the first terminal of the pixel P, the control terminals of the first transistor T1 and the second transistor T2 are coupled to receive the pixel reset signal PRS, and the first main terminal of the second transistor is coupled to receive the pixel reset voltage VPR.

The operation of the embodiment of the cell 2 shown in Fig. 5 will be explained below with reference to the waveforms as function of time t as shown in Fig. 6.

During a reset time interval TR the storage reset switch SR is closed by the storage reset signal SRS, as indicated by a high level of the storage reset signal SRS. Via the storage reset switch SR the storage reset voltage VR, which may be a fixed voltage, is coupled to the second terminal of the storage capacitor C. As a result the control voltage VD at the control terminal of the drive transistor DT will quickly reach the level of the storage reset voltage VR. The storage reset voltage VR is preferably substantially equal to the first supply voltage V1, while the reference voltage Vref is preferably lower than the first supply voltage V1.

Preferably during the same reset time interval TR the pixel reset circuit PRC blocks any current originating from the drive transistor DT and resets the voltage across the pixel P to such a value that the transmission curve of the pixel is at a level of 0% transmission. This may be achieved by a voltage of +5V or -5V as illustrated in Fig. 2. In this embodiment the pixel reset voltage VPR may be selected to be -5V, if the second supply voltage is selected to be 0V. The pixel reset signal PRS has preferably substantially the same timing as the storage reset signal SRS, so as to substantially synchronously reset the storage capacitor C and the pixel P. When the pixel reset signal PRS activates the pixel reset circuit PRC, the first transistor T1 is brought in a blocking state, thereby preventing the current from the drive transistor DT to influence the voltage across the pixel P, while the second transistor T2 is brought in a conducting state, thereby transferring the pixel reset voltage VPR to the pixel P.

During the drive time interval TD the optical display signals Li received by the photosensitive device D result in a photo-current, indicated by an arrow in Fig. 5, which discharges the storage capacitor C. When no optical display signals Li are received the storage capacitor C is not discharged, so the control voltage VD remains constant, indicated by the curve "Li=0". When the optical display signals Li correspond to a maximum level Lmax, the storage capacitor C is substantially completely discharged during the drive time interval TD, resulting in the curve indicated by "Li=Lmax". When the optical display signals Li correspond to a level in-between zero and the maximum level Lmax, the storage capacitor

C is partially discharged during the drive time interval TD, resulting in the curve indicated by "0<Li<Lmax".

During this drive time interval TD a current IL flows through the drive transistor DT and the pixel P. This current IL depends on the control voltage VD. In case Li=Lmax the control voltage VD gradually decreases to a minimum value, which may be the reference voltage Vref, during the drive time interval TD. As a result the current IL increases gradually to a maximum value, resulting in the transmission curve of the pixel P reaching its maximum transmission. So a maximum level of light Lo is transmitted through the pixel. In case Li=0, the control voltage VD is at its maximum value, being in this example the first supply voltage V1 and remains at that value during the remainder of the drive time interval TD. As a result the current IL remains zero and the pixel P does not generate light Lo.

In case 0<Li<Lmax, the control voltage VD decreases gradually to an intermediate value between the reset voltage VR and the first supply voltage V1 during the drive time interval TD in dependence on the control signal Li. As a result the current IL gradually increases to an intermediate value during the drive time interval TD, so the pixel P transmits an intermediate level of light Lo.

So, the level of light Lo transmitted by the pixel P is proportional to the optical display signals Li. A display screen 5 equipped with such cells 2 displays a positive image of an image projected on the screen by the source 3.

As by means of the gain of the driver circuit A a wide range of levels of the electrical signal I may be applied, a low brightness image source 3 may be used to project the optical display signals Li on the panel 1 in order to generate an image with a high brightness.

As an alternative to the embodiment of Fig. 5 the pixel reset circuit may be omitted. In this case the driver circuit A should be provided with an additional transistor, which enables the discharging of the pixel P. Furthermore as the pixel P is no longer reset between two successive images, the driver circuit A should receive a control voltage VD which represents a difference between the pixel voltage VP corresponding to a current image to be displayed and the pixel voltage VP corresponding to the previous image.

It should be noted that the above-mentioned embodiments illustrate rather than limit the invention, and that those skilled in the art will be able to design many alternative embodiments without departing from the scope of the appended claims. In the claims, any reference signs placed between parentheses shall not be construed as limiting the claim. Use of the verb "comprise" and its conjugations does not exclude the presence of elements or steps other than those stated in a claim. The article "a" or "an" preceding an element does not

exclude the presence of a plurality of such elements. The invention may be implemented by means of hardware comprising several distinct elements, and by means of a suitably programmed computer. In the device claim enumerating several means, several of these means may be embodied by one and the same item of hardware. The mere fact that certain measures are recited in mutually different dependent claims does not indicate that a combination of these measures cannot be used to advantage.

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